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Predicting Growth of Mixed-Conifer Species in the Sierra Nevada: rationale and methods

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Forecasting growth and yield of forest stands composed of a mixture of species has always been a difficult forest management problem. This note discusses a method to determine site quality and predict growth of these mixed stands in the Sierra Nevada. The need for reliable growth predictions and the limitations of existing growth and yield prediction methods are discussed. Methods of predicting individual tree growth using soil and topographic factors to quantify site productivity are described.

Retrieval Terms: volume estimation (stands); site class assessment; volume increment (stands); Sierra Nevada Mountains; growth prediction.

Increased pressure to provide more and better products from the National Forests has, in turn, increased the need to intensify forest management. Any effective intensive management program aimed at increasing forest growth, however, requires adequate knowledge of the interrelationships between site conditions and forest productivity. This knowledge exists for some species and for some geographic areas, but is still lacking in the mixed-conifer zone of the Sierra Nevada.

Present methods for predicting growth and yield of these mixed stands lack the flexibility to compare the effects of different silvicultural operations on subsequent stand development and future yields of the component species. This flexibility, however, is needed by forest managers to determine cost-benefit ratios of alternative management practices.

PREDICTING GROWTH IN MIXED FOREST STANDS

The United States Congress has long been concerned that lands capable of producing timber are not

managed at the optimal timber growth rate.[1] This concern helped prompt Congress to enact the Forest and Rangeland Renewable Resources Planning Act of 1974 and the National Forest Management Act of 1976. Federal law now requires land classification, to be completed by 1985, whereby lands capable of growing timber are classified by timber production capabilities. These same laws require that reforestation and timber stand improvement (TSI) funds be used to obtain the best possible timber growth, as determined by cost-benefit analysis. The benefits of alternative reforestation and TSI prescriptions are determined by applying methods that accurately predict timber yield increases obtainable for each type of prescription.

Measuring and predicting forest land productivity are primary to any intensive management program. Reliable site classification methods and accurate evaluation of the effects of silvicultural operations on growth figure importantly in productivity measurements and are now necessary to meet legislated requirements.

Mixed-conifer forests comprise the largest vegetation type in California, covering more than 13 million acres.[2] The composition of these forests is ponderosa pine (*P. ponderosa* Laws.), sugar pine (*P. lambertiana* Dougl.), white fir (*Abies concolor* [Gord. & Glend.] Lindl.), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), and incense-cedar (*Libocedrus decurrens* Torr.), occurring either singly or in mixed associations. This forest type occupies productive land on east-facing slopes of the Coast Range and on west-facing slopes of the Cascades and Sierra Nevada.[3] The best stands are at mid-elevations on the west slopes of the Sierra Nevada where precipitation and seasonal temperatures occur in the most favorable combination.[4] Of the total timber harvested from California's 17 National Forests, nearly 50 percent comes from the six forests that occupy the west slopes of the Sierra Nevada, largely due to the favorable growth conditions there.[5] The expansiveness of the mixed-conifer type and the amount of timber harvested from the west slopes of the Sierra emphasize the need for accurate growth and yield prediction methods applicable to mixed-conifers.

Because of the high variability and complexity of the mixed-conifer type, development of a suitable growth and yield prediction method is far more complex than for traditional simulation methods for pure, even-aged stands. Averages of age, height, and diameter have little utility in growth models for uneven-aged stands. Even where stands are composed of small even-aged groups with a mixture of species, these averages are of little value in determining growth potential of the component trees.

Predicting Productivity

For many forested areas, adequate yield tables exist which give expected volumes per unit of area for a given age, site, stocking, and method of management. These yield tables are, however, almost exclusively applicable to even-aged stands predominantly of one species, for two reasons: average age must be determined and generally a height-age relationship is used for site classification. Predicting growth and yield of uneven-aged stands is much more difficult: average stand age is not a usable variable and site index, which is an age-dependent variable, is questionable.[6] The same problem exists in forests that are comprised of small even-aged patches where intolerant species are present. The height growth of a species in this type of stand is often more closely related to its position within the stand and to the varying stand conditions by which it has been affected during its life, than to age.[7]

Site index poses other problems as an expression of potential productivity within the mixed-conifer type. The site index method classifies productive stand potentials in terms of height growth, yet we are interested here in determining volume production. Stands with equivalent site indexes are not necessarily equivalent in volume production; height growth of a species may be the same on two different sites, but the mean annual volume increment may be significantly different.[8] Diameter growth must therefore be considered along with height growth to determine potential productivity. Site index curves, and the yield tables developed from them, are based on heights of dominant and codominant trees. If those trees are removed by logging or thinning, then even very careful measurement of remaining trees will not indicate the true potential height growth of the stand.[9]

Yield tables for second-growth mixed-conifer stands in California have used the site index approach.[4] Usefulness of these tables becomes highly questionable, however, considering irregularity in stocking and age structure, species of differing silvical characteristics, and the difficulties associated with site quality evaluation of these mixed stands. Stands in mixed-conifer forests are seldom uniform in age. Many stands are made up of small even-aged groups, and others are irregular in age (all age classes are rarely present as in a true selection forest).[4] Adding to the complexity of age distribution, individual species appear in mixed-conifer stands in incalculably varying proportions.

Individual Tree Approach—An Alternative Solution

To avoid stand averages, the most feasible growth and yield prediction method for mixed-conifers appears to be stand simulation using individual trees as the basic elements. Much of today's simulation work was not possible a few years ago because both the technology and personnel were not available. But sufficiently high level programming languages are now part of the daily forest mensuration and management activities.[10] For this reason, computer technology has made individual tree methods more appealing. Not that the concept of the individuality of trees and stands which make up a forest population is new: computer science has simply made more complex analytical procedures feasible and the processing of large quantities of information easier.

Yield prediction by individual tree simulation typically includes three component models:

- Growth of individual trees during a prediction period.
- Regeneration, including growth into existing stands during the prediction period.
- Periodic mortality, including scheduled harvests during the period.

The growth model for development of individual trees is a set of functions that predict changes in tree diameters, heights, and crowns during the next growth period. Once these growth function equations are derived for each species, they can be fitted into existing simulation models such as Stage's "prognosis" model, which is available as a complete computer system.[11] This system simulates growth of the sample trees through a projection period based on their potential growth functions and projects each sample-tree record to a trees-per-acre basis. Thus, the basic unit of study here is the tree, and the development of a stand is, accordingly, the sum of the development of its component trees.

Methods of Site Evaluation

Regardless of the method to predict growth and yield of forest stands, some measurement or classification of site quality must be used in the prediction. Site quality is determined by the combined influence of all site factors that directly or indirectly affect the nature of the site. Where site index is used to make this classification, the tree is considered an integrator of these site factors and site quality is expressed in terms of height attained at a given age.

The presence, abundance, and constancy of occurrence of various plant species can also be considered an integrated expression of the combined influence of site factors. This measurement is used in some areas as an index of site quality. Vegetal, or habitat type, mapping, based on understory and overstory vegetation, has been used to classify forest sites in the western intermountain area. Daubenmire[12] related height growth of ponderosa pine to these habitat types in eastern Washington and northern Idaho. Pfister and others[13] developed yield capability estimates for habitat types in several National Forests in Montana, and Stage[14] developed equations predicting height increment for ten conifer species distributed among 10 habitat types in northern Idaho and western Montana. It is important to note, however, that most of Daubenmire's critics feel that his habitat system is difficult to use, and even more difficult to extrapolate outside of the intermountain area, for two reasons: he spent nearly a lifetime setting up the system and he dealt with minimally disturbed stands.

A meaningful site quality classification system has not been developed for Sierra Nevada habitats, largely due to the disturbed conditions from heavy timber cutting during the gold rush and construction of the Southern Pacific Railroad through the Sierra.

Where suitable indexes of site are not available, an alternative to site quality assessment is to measure the intensity of major factors influencing tree growth on a given site. The factors selected for measurement in similar studies have been those which can become limiting to the biological growth processes.[15] These factors, such as steepness of slope, aspect, depth and texture of the soil, and elevation, generally have no direct effect on tree growth, but act indirectly by influencing moisture, temperature, light, and other chemical and physical agents of the site.

Growth predictions for individual trees within the study area can be made once the correlation between growth rates and measured values is determined for the site factors and values for these factors are known. These values thus become the independent variables of the growth prediction equations. Since the factorial approach to site quality evaluation is based on relatively stable features of the environment, such as soil and topography, and not on current vegetational characteristics, this method can be applied to disturbed or undisturbed sites with pure even-aged stands or stands composed of a mixture of ages, species, and sizes. Thus, the first, and probably most important, step in obtaining a yield prediction system is to derive growth prediction equations for individual tree species based on data collected from the area under analysis.

METHODS

Study Area

The study area occupies mid-elevations on the west slope of the Sierra Nevada. Data is being collected within the boundaries of the six National Forests which occur there. From north to south, the area extends about 350 miles from the northern boundary of the Plumas National Forest to the southern boundary of the Sequoia National Forest. The other four National Forests within the study area are the Tahoe, Eldorado, Stanislaus, and Sierra. Within this area, elevational limits of the mixed-conifer type vary with changes in latitude and aspect, but most of the type occurs between 3000 and 7000 feet *(fig. 1)*.

Scope

Young-growth stands of mixed-conifer which fit the definition given for the ponderosa pine–sugar pine–fir type (type 243) by the Society of American Foresters[16] are being sampled throughout the study area. Young-growth stands, as defined for this study, are those with greater than 75 percent of their basal area comprised of trees less than or equal to 80 years old at breast height.

Plantations within the study area are not sampled. The seed source for many plantations is unknown and the applicability of their current growth rates to the natural range of the mixed-conifer is problematic.

This study deals only with the development of growth functions for individual trees. Models for stand regeneration and mortality will be developed through additional silvicultural research.

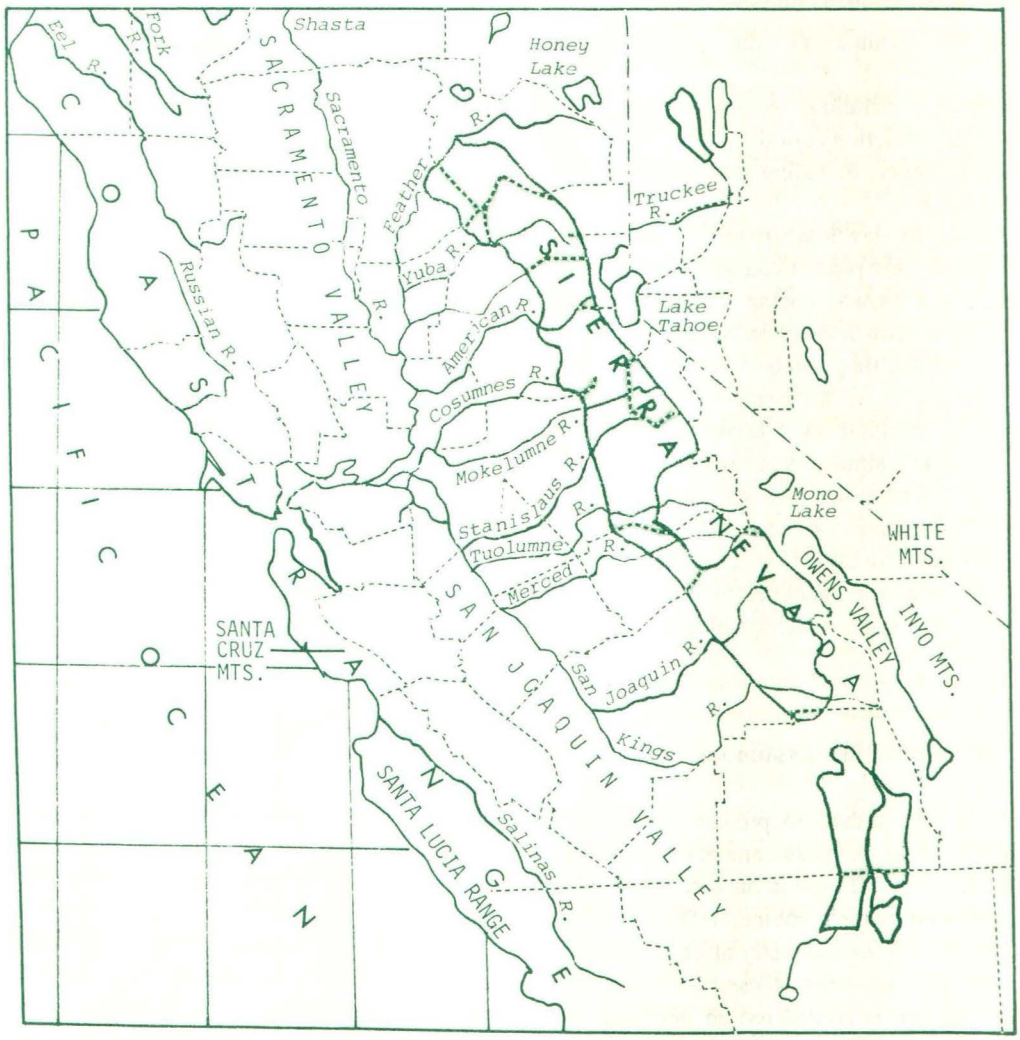

Figure 1—Approximate boundary of study area.

Selecting Sample Locations

Plot locations are selected randomly within the mixed-conifer type. Random numbers, representing X and Y coordinates, are generated for each timber type map that contains mixed-conifer stands. Where timber type information is available on the Wildland Resource Information System (WRIS), the computerized mapping system,[17] all points with coordinates outside a mixed-conifer delineation are automatically rejected. Where WRIS timber type maps are not available, this screening process will be done manually. Due to the emphasis of the study on young growth, sample points are not selected in stands of large sawtimber.

Field Location and Layout of Sample Plots

Each randomly selected point, defined by the map coordinates, is plotted on a topographic map and on an aerial photograph. Both the map and photo are used for field location of the sample point. At each point, a cluster of five plots arranged in an L-shape is used to sample the variability in growth rates, species composition, and density within the stand. Plot centers are located 132 feet apart along north and east compass lines. This five-point cluster arrangement is used in the Pacific Southwest Region's compartment inventory program.

Plot Measurements

Tree data

At each plot center, the basal area/acre is determined by counting all "in" trees with a wedge prism. Each tree is listed on a tally sheet and the following observations are recorded:

- Species
- Diameter breast height (outside bark)
- Position, damage, defect, and tree class
- Age at breast height
- Total height from base to tip of tree
- Height to base of the live crown
- Type and extent of insect or disease impact.

One increment core is measured to determine radial growth on each tree greater than 3 and less than 6 inches d.b.h. and at least 10 years old at breast height. Two cores, taken at right angles, are measured on all trees greater than or equal to 6 inches d.b.h. Radial growth for each 10-year period is measured to the nearest 0.05 inch, using a hand lens when necessary.

Site factors

Major environmental characteristics of the site are determined on a 1/5-acre circular plot, including:

- Slope percent, measured with a clinometer along the line of slope passing through the plot center;
- Aspect, measured with a hand compass along the line of slope and recorded as azimuth from true north to the nearest degree;
- Ground cover, percent estimates of ground covered with live vegetation, litter, rock, and bare ground;
- Vegetation composition, identification of all trees and shrubs which occur on the 1/5-acre and estimates of the percent composition of each.

Site factors recorded for the entire plot cluster include:

- Elevation of the vertex plot of the L-shaped cluster, determined from U.S. Geological Survey maps and recorded to the nearest 100 feet;
- Precipitation zone in which estimates of average annual precipitation are obtained from isohyetal maps of California[18] and recorded to the nearest inch;
- Soil characteristics near the center of that plot which appears most typical of the cluster. Pits are dug to a depth of 48 inches, or to bedrock, whichever occurs first. The soil epipedon and diagnostic horizons are described and representative samples of each horizon are collected for particle size analysis in the laboratory.

Stem analysis data

An average of two trees per plot, selected at random from the prism tree tally sheet, will be felled for collection of stem analysis data. Felled trees will be sectioned at predetermined points along the stem to determine the following characteristics:

- Total stem length
- Height growth during the last two 10-year growth periods
- Radial growth along the stem during the last two 10-year growth periods
- Bark thicknesses along the stem
- Wood volume at present and 10 and 20 years ago
- Location and extent of insect or disease damage during the last 10-year growth period.

DATA ANALYSIS

Prediction equations for each of the tree growth components—height and diameter—will be developed through multiple regression analysis. The first phase of analysis will develop equations for predicting rate of increase of tree diameters (10-year periodic diameter increment) for each mixed-conifer species. Values of the dependent variable—periodic diameter

increment—will be computed from the increment core measurements of radial growth. Independent variables which will be tested for significance in the regressions include site factors (soil depth and texture, elevation, slope percent, and aspect), stand density (basal area/acre), and tree characteristics (present d.b.h., percentile in basal area distribution, crown ratio, and insect or disease impact).

The second phase of analysis will develop equations for predicting periodic height increment for each species. Values for the dependent variable (10-year periodic height increment) will be obtained from stem analysis data. Other independent variables to be tested in the regression will include concurrent diameter increment and tree height. Transformations of the variables will be used, where appropriate, to obtain the best correlations.

Form factor equations, developed for each species from stem analysis data, will determine present and predicted volumes of individual trees. Bark ratios will be derived from bark thickness measurements on each stem analysis tree. If outside bark diameters are measured to determine current and predicted tree volumes, these bark ratios will be used to reduce volume estimates by the percentage of bark on the total stem.

DISCUSSION

Present methods to derive growth prediction equations for the mixed-conifer species in the Sierra Nevada depart from traditional approaches to growth and yield prediction in four major ways.

The major difference is the method of plot and tree selection. In the majority of growth and yield studies, sample sites are chosen where stand densities, age structures, and species composition are within narrowly specified limits. Trees measured for growth on these sites are generally dominants or codominants which have no evidence of damage such as forked or broken tops, or reduced growth rates due to insects or diseases. In other words, many growth predictions are made for hypothetical stands composed only of healthy, undamaged trees. The growth predictions developed in this study will be based on the measurements of all trees on randomly selected plots. Thus, the predictions will apply to tree and stand conditions as they actually exist and not just to the desirable but normally unattainable "ideal" conditions.

Second, pest incidence and severity information is collected concurrently with the tree growth data. Each sample tree is rated by type and degree of insect and disease damage using a Pest Damage Rating System. Expertise in entomology and pathology is provided through a cooperative agreement with the Forest Insect and Disease Management Staff of the Forest Service's Pacific Southwest Region. Inclusion of pest data in the analysis will allow for development of growth loss estimates due to forest pests. These estimates can then be used to determine cost-benefit ratios for proposed pest management practices.

Third, soil and topographic factors are independent variables for predicting individual tree growth. Many soil-site studies have been conducted in the United States since the mid-1930's which statistically relate selected environmental factors to site quality.[19] All of these studies, however, express site quality in terms of site index, not in terms of intrinsic volume productivity of the site.

Fourth, the sample plot layout and measurement procedures of this investigation are, in most cases, identical to those used in the Pacific Southwest Region's Compartment Inventory and Analysis program. Growth predictions developed through this research will be easily applied to compartment inventory data with sound reliability since the same sampling design is used. A major weakness of many growth models is that variables and their method of measurement are not the same as those used in the inventory to which the growth projections will be applied.

CURRENT RESEARCH STATUS

In 1978, project field work was begun on the Eldorado National Forest. Field crews visited approximately 450 randomly selected plots within the mixed-conifer type. Of these 450 plots, 157 were found to be in young-growth stands. Stand, tree, and site factors were measured and recorded at each plot. Felling of sample trees and collection of stem analysis data began in May 1979. During the current and future field seasons, randomly selected plots will be measured on the other National Forests of the westside Sierra Nevada.

Statistical analysis of initial field data is not completed; therefore it is difficult at present to enlarge upon the relationship between dependent and independent variables, or to evaluate the methods to predict forest productivity. Preliminary results, in the form of growth function equations applicable to the Eldorado National Forest, may be ready for release in early 1980.

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